AD-A262 259

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED FINAL/15 May 89 TO 31 Mar 92
4. TITLE AND SUBTITLE INTEGRATED APPROACHES TO PARALLELISM IN OPTIMIZATION & SOLUTION OF INVERSE PROBLEMS (U)		5. FUNDING NUMBERS 2304/A4 AFOSR-89-0363
6. AUTHOR(S) Professor William Symes		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Rice University Dept of Mathematical Sciences Houston TX 77251-1892		8. PERFORMING ORGANIZATION REPORT NUMBER AFOSR-TR-
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NM 110 DUNCAN AVE, SUTE B115 BOLLING AFB DC 20332-0001		10. SPONSORING/MONITORING AGENCY REPORT NUMBER AFOSR-89-0363
11. SUPPLEMENTARY NOTES		
12a. DISTRIBUTION/AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED		12b. DISTRIBUTION CODE

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13. ABSTRACT (Maximum 200 words)

Mathematical models for mechanical design problems and development of analytical and numerical tools for their solution was studied under this grant. The mathematical problems separate into ones of rods and membranes. Regarding the former, with M. Overton the PI provided the first rigorous study of the shape of the strongest rod. In particular, within the context of the Euler-Bernoulli model, it was established existence, necessary conditions, regularity, and a general, though efficient, means of computing an optimal shape. Previous studies had not fully dealt with the fact that the strength of a rod (the axial load under which it commences to buckle) need not be a differentiable function of its shape. The Mathematical Intelligence solicited an expository account of this work. This article was picked up by Discover magazine, where the review appears. Engineers in off-shore oil rig design at Exxon Production Research in Houston have approached the PI regarding the research. Via the rolling of thin plates they have the means to create rods with piecewise conical cross-sections. With J. Maddocks the PI has extended all of the above analytical findings to a much richer class of rods. In particular, they are able to accomodate hyperelastic rods with nonlinear bending laws and vanishing cross-sections in both the interior and at the boundary. In this new framework they are also finally able to carefully pose and settle the bifurcation question as to whether the branch(es) of equilibria stemming from the buckling load of the optimal column are indeed supercritical, i.e., rightward

93-06627

93 3 31 065

14. SUBJECT TERMS			15. NUMBER OF PAGES 2
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR(SAME AS REPORT)

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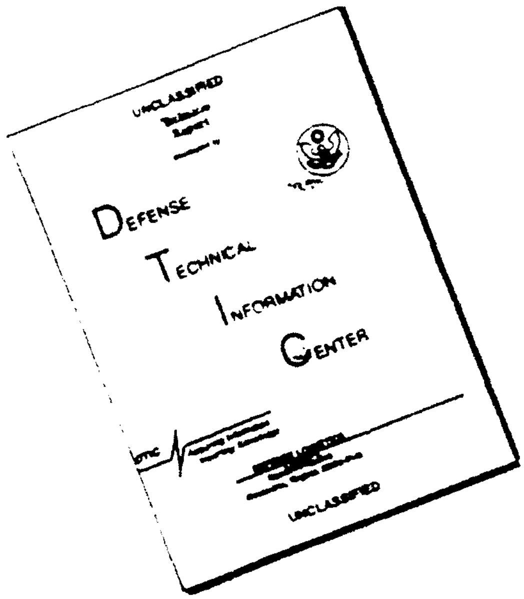

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Final Report - AFOSR Grant 89-0363 January 1, 1993

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Under this grant I studied mathematical models for mechanical design problems and developed analytical and numerical tools for their solution. The mechanical problems separate into ones of rods and membranes.

Regarding the former, with M. Overton, I provided in [1] the first rigorous study of the shape of the strongest rod. In particular, within the context of the Euler–Bernoulli model, we established existence, necessary conditions regularity, and a general, though efficient, means ot computing an optimal shape. Previous studies had not fully dealt with the fact that the strength of a rod (the axial load under which it commences to buckle) need not be a differentiable function of its shape. The Mathematical Intelligencer solicited an expository account of this work, [2]. This article was picked up by Discover magazine, where the review [3] appears. Engineers in off-shore oil rig design at Exxon Production Research in Houston have approached me regarding this work. Via the rolling of thin plates they have the means to create rods with piecewise conical cross-sections. With J. Maddocks in [4], I have extended all of the above analytical findings to a much richer class of rods. In particular, we are able to accommodate hyperelastic rods with nonlinear bending laws and vanishing cross-sections in both the interior and at the boundary. In this new framework we are also finally able to carefully pose and settle the bifurcation question as to whether the branch(es) of equilibria stemming from the buckling load of the optimal column are indeed supercritical, i.e., rightward.

Regarding membranes I have contributed to two problems. In [5] I describe how to distribute a prescribed amount of two materials throughout a given planar shape in order to minimize the fundamental tone of the resulting membrane. Having provided definitive results on the symmetry, regularity, length, and computation of the interface between the two constituents in the optimal layout, I believe there is little else left to say about this problem. In [6], with M. Ross, I have established existence and partial regularity, via necessary conditions, for the problem of extremizing as a function of shape alone an arbitrary membrane frequency. Previous attempts by others have only succeeded in minimizing Dirichlet eigenvalues and maximizing Neumann eigenvalues. Our setting, of planar starlike domains of fixed area and bounded perimeter, allows one to extremize either type of eigenvalue, in either direction. As the higher frequencies may be multiple, the obstacle to deriving necessary conditions is that these frequencies need not depend differentiably on the shape of the membrane. This issue, of characterizing the generalized gradient of a multiple eigenvalue, was in fact still open even in finite dimensions prior to [7], where [5] is surveyed and partially extended to the higher eigenvalues and the (finite dimensional) foundation for [6] is laid.

The work I completed and began under this grant lead to my being awarded a 1992 National Young Investigator by the National Science Foundation.

[1] S. Cox and M.L. Overton, *On the optimal design of columns against buckling*, SIAM J. Math. Anal. 23(2), pp. 287-325, 1992.

[2] S. Cox, *The shape of the ideal column*, Mathematical Intelligencer 14(1), pp. 16-24, 1992.

[3] Breakthroughs, Mathematics, Discover, June, 1992.

[4] S. Cox and J.H. Maddocks, *The optimal design of a nonlinear elastica*, in preparation.

[5] S. Cox, *The two phase drum with the deepest bass note*, Japan J. Ind. and Appl Math. 8(3), pp. 345-355, 1991.

[6] S. Cox and M. Ross, *Extremal eigenvalue problems for starlike drums*, in preparation.

[7] S. Cox, *Extremal eigenvalue problems for the Laplacian*, proceedings of *Recent Advances in PDE*, El Escorial, Spain, July, 1992, to appear.